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Central Eurasia: ALTERNATE ENERGY

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CENTRAL EURASIA: ALTERNATE ENERGY

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Nontraditional Power Engineering: Myth, Reality, Capabilities

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[A series of three articles by Candidate of Technical Sciences P.P. Bezrukikh]

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[Text] It would probably be appropriate to start with apologizing to the readers for the tedious necessity of explaining certain terms and concepts.

Alas, even the experts cannot agree on unified terminology. So the pages of newspapers and magazines are littered with such word combinations as "nontraditional power industry," "small-scale power industry," "large-scale power industry," and "renewable energy sources." In layman's terms, the difference between "large-scale" and "small-scale" power industries can be defined as follows.

While "large-scale" power engineering involves boilers, turbines, and generators with an output of tens and hundreds of thousands of kilowatts, small-scale power engineering operates with the same devices whose capacity is measured in tenths and hundredths, or units of a single megawatt.

Whereas large-scale power engineering covers large nuclear, thermal, and hydroelectric power plants and boiler rooms, small-scale power engineering deals with diesel, gasoline, or gas-turbine power plants, small hydroelectric plants, and small boiler rooms.

Whereas large-scale power industry means providing electric and heat power to large industrial centers and enterprises, to cities and towns, and to large villages and settlements, and electric power lines with a rating of 35 to 1,150 thousand volts linking power plants to users, small-scale power engineering entails power supply to individual users, productions, and units linked to the power plants feeding them by transmission lines with a rating of 0.4 to 10 kV.

Somebody once classified the plants and devices utilizing the wind, water, sun, biomass, and geothermal energy as well as the heat contained in the earth, air, and water as nontraditional power engineering.

True, wind and water mills have been known since times immemorial and in this sense, they are indeed anything but traditional. Of course, the most appropriate name for them would be renewable energy sources, as they are commonly referred to abroad. This is to distinguish them from the nonrenewable energy sources, i.e., coal, oil, and gas.

At this point, I should mention that some 30-40 years ago, wind and water mills and even most of the small hydroelectric plants were swept away by the wave of myopia, so today, a return to using the wind, sun, and water energy is occurring at a new, higher level of scientific and engineering development. And only from this viewpoint can these plants be referred to as nontraditional.

Is there room for nontraditional power engineering? It can become an integral part of the large-scale power industry as happened to a lion's share of wind power plants, wind farms, and geothermal electric power plants within the power grids in the State of California (United States) and in Denmark, Iceland, and a number of other countries.

Yet the principal application of nontraditional power engineering are not in energy supply to large cities and enterprises but in meeting the direct daily and production needs of mankind, power supply to small productions and enterprises in the so-called self-sustaining power supply zones, i.e., areas not linked to regional power grids.

Yet we cannot avoid answering one of the most important questions: Is the nontraditional power industry capable today or in the near future of becoming an alternative to nuclear or fossil fuel energy?

Can Wind Power Technology Quench the Thirst for Energy?

As an engineer who has spent may years working in large-scale power engineering and is now examining the issues of nontraditional power engineering, I can answer: unfortunately, not today. Judge for yourself. The output of a standard nuclear power plant generating unit is 1,000 MW. The highest power of the pilot prototype of the Raduga Moscow Design Office (MKB) wind power plant design currently under production is 1 MW. One megawatt of installed capacity at a wind power plant is two to three times more expensive than that in a nuclear power plant while it produces two to three times less electric energy during the year. Thus, instead of one nuclear power plant generating unit, we would have to install 2,000 to 3,000 wind power plant generating units.

One cannot say that this is mission impossible, but this calls for time and resources to set up mass production and construction. Yet this is not even the most important obstacle. Wind power plants can generate energy only when there is wind, while nuclear power plants generate all the time, except two months a year. Storing large quantities of wind power plant energy also turns into a serious problem which requires time and money.

We should note that quantum leaps caused by breakthrough inventions occur in the development of engineering, but this does not happen often. So in the field of wind power engineering, there is an inventor from Urengoy who is promising to develop a 10-MW generating unit off the bat, which is 10 times more powerful than the existing unit designed by the Raduga Moscow Design Office. There is enough doubt that he will succeed. Yet this idea can be confirmed or disproved only by a pilot prototype. To develop a pilot prototype, the inventor needs about 2 billion rubles (in 1992 prices). And he is hoping to raise this sum from enterprises. We should wish him luck since the state cannot put such an amount of money at risk.

And here is another "killer" argument, and not in favor of nontraditional power engineering. The predicted level of primary energy resources consumption in Russia in 1993-1995 is at the 1,200 million tons level of equivalent fuel. The annual volume of fossil fuel substitution with nontraditional power industry devices in Russia may by some estimates reach 0.6 million t, which is 0.05% of the total energy resource production. From this viewpoint, the issue of the nontraditional power industry development may be classified as secondary.

Yet the urgency of the issue is determined not by today's status and not even by its weight in the total energy balance but by the role which nontraditional power engineering may play 10 to 15 years from now (20 to 25 million tons of equivalent fuel). This proportion is only one-half of the volume of fossil fuel substitution by nuclear power plants.

And here, a far-from-irrelevant question arises: What kind of resources do we possess?

We distinguish between gross (theoretical), technical (feasible), and economic potential of renewable energy resources.

The gross (theoretical) potential is the total energy contained in a given type of energy resource.

The technical potential is the quantity of energy which may be obtained from a given type of energy source at the existing level of scientific and engineering development. It varies from a fraction of a percentage point to 10% of the gross potential, but it constantly increases with the advances in equipment production and the introduction of new technologies.

The economic potential is the quantity of energy whose derivation from the given type of energy source is economically efficient at the existing correlation of prices for equipment, materials, and labor. It amounts to a certain fraction of the technical potential and also increases with advances in equipment production. The economic potential of nontraditional renewable energy sources in Russia measures on the order of 300 million tons of equivalent fuel, i.e., 25% of the total energy consumption. So "the game is worth the candle."

Even today, at today's economic conditions, there are areas of economically feasible application of nontraditional energy sources in each Russian region. The need to develop the nontraditional power industry must be considered primarily in the regional energy balance from the viewpoint of the task of the Russian rural revival.

Rural renaissance in our country is possible on the basis of reliable power supply which meets the demands in heat, cold, hot and cold water, electricity, and cooking at the level of today's working and living conditions. Depending on the region, the solution to this problem is characterized by certain peculiarities. A scientific and technical policy based on the concept of comprehensive approach to residential power supply should be aimed at implementing this policy.

Role of Nontraditional Power Industry

First, many Russian regions, such as the Far North, Far East, Siberia, Yakutia, Buryatia, and Altay as well as the central regions are located in the zones of decentralized power supply.

Due to the low population density, construction of large power plants and transmission lines in these regions is not always economically feasible and cannot be implemented in the next decade. Diesel- and gasoline-powered power plants which provide electricity to large inhabited localities in these regions consume a large quantity of liquid fuel. Allowing for its delivery, the cost of 1 tons of fuel is high, and the price is continuing to rise, while shipment disruptions are becoming increasingly frequent. Stable power supply to these regions is in a combination of various types of traditional and nontraditional energy sources.

Second, centralized power supply in certain rural zones is characterized by frequent user disconnections due to the poor network condition. This results in considerable losses in livestock, poultry, and dairy farming and in production of other foodstuffs. In such regions, nontraditional energy sources play the backup role. Naturally, in so doing, the issue of storing energy and the possibility of transmitting excess energy to the network must be resolved.

Third, a complex environmental situation has developed in a number of towns and recreational zones due to harmful discharges into the atmosphere by industrial enterprises and boiler rooms. Here, heat generation for hot water supply and heat supply with the help of nontraditional energy sources is a preferable if not the only possible method. A comprehensive approach to this problem will make it possible to eliminate numerous small, uneconomical boiler rooms whose specific equivalent fuel consumption in boiler rooms exceeds 300 kg/Gcal and prevent atmospheric pollution.

Fourth, in all regions of the country, there is a problem of providing heat to individual residences, temporary work sites and recreation areas, and garden cottages and obtaining hot water for domestic purposes. Up to 50% of these needs may be met by nontraditional energy sources.

Such an approach to supplying power to the population and thus developing the nontraditional power industry may have an overall impact of improving the working, living, and recreation conditions of approximately 80 million people, including a rural population of 40 million, in the nearest decade.

What is required for accomplishing this? To develop an industry and its infrastructure and provide state financial support at the early stages--in 1993-1995.

There are many aspects of the scientific and technical policy toward the regions characterized by decentralized power supply as well as unstable power supply and environmentally unfavorable conditions: developing the equipment, setting up its mass production, assembling, repairing, and maintaining the units, providing state financial support to organizations and persons, and finally, the issue of economic efficiency of utilizing the nontraditional renewable energy sources (NVIE).

In addition to the aforementioned considerations, economic estimates of plans to utilize nontraditional renewable energy sources drawn in 1986-1989 in the framework of the European Economic Community Commission are interesting from the economic efficiency viewpoint. They contain data on the pay-off periods: two-to-four years for burning wood chips from a lumber yard boiler room: five years for a biogas unit with a flexible plastic methane tank (biological reactor) with a 20 m^3 volume at a small poultry farm and biogas combustion in a boiler room: three years for a biogas plant with a 200 m^3 methane tank at a large poultry farm (100,000 laying hens) utilizing biogas in the boiler and a 135-kW motor-generator: eight years for a bioenergy power plant with a methane tank volume of 210 m^3 for processing manure from private rural farms which includes 160-kW wind power plant and a 15-kW biogas-driven motor-generator: seven years for an absorption heat pump for heating a private home employing the ambient air heat: four-and-a-half years for a heat pump plant for heating an eight-apartment building utilizing ambient air heat: seven-to-eight years for buildings with a reduce energy consumption employed improved heat insulation, solar collectors, and heat pumps: eight-to-ten years for wind power plants linked to energy grids: and two-to-five years for hot water supply systems with solar collectors designed by various companies.

As we can see, the pay-off period for most diverse projects employing nontraditional renewable energy sources in the European countries does not exceed or is considerably lower than the pay-off time of the energy-consuming installations.

The reason for this situation is commonly known--the existing correlation between the cost of equipment and the price of fuel and energy which force the consumers to save energy resources.

Until recently, the picture at home was the exact opposite, although much has changed in the last year. One cannot state that we have achieved a correct correlation of the fuel and equipment prices and the cost of labor. But the situation is gradually changing in favor of the nontraditional power industry development.

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[Excerpt] Small-Scale Power Industry

Today, there are no acknowledged unified criteria for classifying hydroelectric power plants (GES) as small. Conventionally, we regard hydroelectric power plants with a power of 0.1 to 30 MW as small, whereby constraints are set on the hydraulic turbine impeller diameter of 2 m and the hydroelectric generating set unit power of up to 10 MW. Hydroelectric power plants with an installed capacity of less than 0.1 MW are classified as microhydroelectric power plants.

In the Bolshaya Sovetskaya Entsiklopediya (large Soviet encyclopedia of 1972), the (gross) hydroelectric energy potential of large and medium rivers in the USSR is given as 3.338 billion kWh (3,932 billion kWh according to other sources), while the economic potential of the hydroelectric energy sources is estimated (in 1965) as 1.095 billion kWh. Moreover, in 1969, the economic potential utilization in the USSR amounted to 10.5% vs. 37% in the United States, 69.3% in Canada, 60.5% in Japan, 75% in France, and 85.5% in Switzerland.

In the territory of the former USSR, the technical potential of all hydroelectric resources is estimated as 2.145 kWh of which technically, small hydroelectric power plants can muster 500 billion kWh, i.e., 23%. At today's average specific consumption of fossil fuel power plants, the fossil fuel substitution volume at such generation levels amounts to roughly 160 billion tons of equivalent fuel, whereby Russia's share is on the order of 100 billion tons of equivalent fuel.

The small and microscopic hydroelectric power plant potential contains the following energy sources: sections of small and medium rivers, upper parts of large rivers, the unutilized potential of large rivers, water project reservoirs, canals, industrial waterworks systems, and municipal and domestic water supply systems. In other words, such hydroelectric power plants can be constructed virtually in all Russian krays, oblasts, and republics.

Today, small-scale hydroelectric engineering is seeing the third phase of its development history. Construction of the first hydroelectric power plants began in the last century when they were intended for supplying electric power to individual plants and villages. Then the pace of their construction was slowed down due to competition from small thermal power plants. The first phase of large-scale construction of small hydroelectric power plants occurred in the late 1940s and early 1950s when thousands of small hydroelectric power plants were being built in the USSR and other countries. Here, they were built by collective and state farms, enterprises, and the state. In the 1960s and 1970s, hundreds and thousands of small hydroelectric power plants were decommissioned and either mothballed or eliminated due to the rapid onslaught of large-scale power engineering on the basis of large fossil fuel, hydroelectric, and nuclear power plants.

Naturally, during the new third phase, revival of small hydroelectric power plants was possible only at a new engineering level of basic equipment, primarily at a new level and degree of automation.

It would be useful, however, to revisit the not-so-distant past. In 1952, there were 6,614 small hydroelectric power plants with a total capacity of 332 MW and by 1959, the number of hydroelectric power plants was reduced to 5,000, while their total power increased and reached 481.6 MW. By 1986, when development of the program of reviving small hydroelectric power plants got underway, their total number shrunk to 334, while the total power increased to 1,434 MW, i.e. the relatively large plants "survived" among the small ones. On the nationwide scale, the 1986 program called for recommissioning, upgrading, and overhauling small hydroelectric power plants with a total power of 2,200 MW in 1988-2000. Today, the former republics are reevaluating their programs. The start of active work on microhydroelectric power plants dates back to 1986. In 1988, the Energozapchast parts plant in Cheboksary began mass production of sleeve-

type microhydroelectric power plants with a 1.5-kW power, while at the same time, the Kharkov turbine plant and Leningrad Metalworks began production of microhydroelectric power plants (5.5 and 4.5 kW, respectively). The following plants may start mass production of equipment for microscopic and small hydroelectric power plants with various heads and flow rates: the Kompaktenergo Engineering Association (with a 120-600 W power), the INSET Scientific Engineering Association (with a 0.05-0.5-kW and 30-275-kW power), the Production Association of the Leningrad Metal Works (with a 0.5-4-kW, 1,200-1,500-kW, and 1,400-1,600-kW power), the Energozapchast plant (with a 0.1-0.5-kW power), the KEVREN small enterprise (with a 4-7-kW power), the Nerey scientific production enterprise (with a 12-21-kW power), the Uglich power engineering plant (with 40-100-kW power), the Kharkov turbine plant (with a 100-200-kW, 250-300-kW, 2,000-3,500-kW, 3,000-4,500-kW, and 4,000-6,000-kW power), the Syzran turbine plant (with a 400-600-kW, 500-800-kW, 800-2,400-kW, 1,000-1,500-kW, 1,500-4,500-kW, 3,000-4,000-kW, 3,500-5,200-kW, and 7,000-11,000-kW power), and a number of other organizations. Furthermore, it is expected that the following organizations will produce prototype batches: the TETA Technical Association (with a 0.4-0.6-kW, 4-6-kW, 2-25-kW, 10-100-kW, and 50-600-kW power), the ENKO production and design plant (with a 1.4-kW, 1.5-40-kW, and 160-250-kW power), and some other organizations.

Annual production of microhydroelectric power electric power plants of varying power has reached some 700 items. By examining these data, one has reason to state that the most important steps for the small and microscopic hydroelectric power plant development have been taken. Given the desire, there are places where equipment can be procured. Again, the problem is in getting the orders.

Geothermal Power Engineering

Depending on the method of their utilization, the technical potential of geothermal waters is estimated on the following scale: three for gusher hole operation, 30-40 for suction pump delivery, and 130-150 million tons of equivalent fuel per year for the circulation technology with a return pumped delivery of spent water, whereby Russia's share is on the order of 100 million tons of equivalent fuel. Geothermal waters are primarily used for constructing heating and hot water supply plants. In addition to hot water, a steam and water mixture--the so-called "geothermal steam and water"--are recovered from the ground in some regions (Kamchatka, Kuril Islands, and some other locations). The energy potential of these resources, primarily in Kamchatcka and Kuril Islands, is estimated at 900-1,000 MW. In terms of equivalent fuel, likely fossil fuel savings are not so large--approximately 2 million tons per year. Yet for the region, this means fully meeting all energy demands. The use of geothermal energy, however, created a complex situation. Efforts to master the geothermal resources are underway in Krasnodar and Stavropol krays, Kabardino-Balkaria, Northern Osetia, Checheno-Ingushetia, Dagestan, Kamchatka, and Sakhalin as well as former USSR republics. Installations utilization geothermal heat can be found in all of these regions. For example, 120 different users utilize geothermal waters in Dagestan, including municipal and household customers, heating systems, production processes, greenhouses, and mud baths. Thus, hot water supply to the town of Izberbash with 25,000 residents is fully provided by geothermal waters with a small system makeup from boiler rooms during the winter months. Available explored resources in the country make it possible to ensure geothermal water

production on the scope of 90,000 m^3/yr. Yet in recent years, production has declined from 60.8 million m^3 in 1988 to 57.4 million m^3 in 1989, 55 million m^3 in 1990, and 45 million m^3 in 1992. Production capacities of more than 30 million m^3/yr have been mothballed because the users were not ready. This is where the lack of ownership is being felt. The overall number of greenhouses heated with geothermal waters (80 ha) and provision of hot water to residents (350,000 persons) have declined throughout the country in the past four years. The resolutions to switch the town of Groznyy to geothermal heat supply have not been implemented.

Geothermal power engineering capabilities. The installed capacity of the Pauzhet geothermal power plant in Kamchatka is 11 MW, and its actual load which is not being fully utilized is 5 MW. It is expected that the station power will be boosted by 6 MW in 1993-1995.

Due to a number of unresolved financing issues and design solutions, construction of the Mutnovo geothermal power plant is being delayed: its first generating unit was expected to be commissioned in 1992, but this is unlikely to happen in 1994.

Geothermal power engineering development calls for a principal reevaluation of the design philosophy and a transition to construction of geothermal stations on the basis of packaged modular generating units. There is a basis for such a design.

There are some encouraging moments in this otherwise sad picture. Despite numerous difficulties, including financial problems, construction and equipment development for the experimental pilot geothermal power plant with a 2-MW power is continuing on the basis of underground circulation systems in Stavropol kray; its start-up is expected in 1995. Technical proposals have been developed for constructing a geothermal heat and power supply plant in Buryatia with a 3-MW electric power and 12-MW thermal power.

A whole range of generating units intended for installation in the Kuril Islands, Kamchatka, and Latin America are in various production stages from engineering design to fabrication at the production association of the Kaluga turbine plant. These include 0.5-, 1.7-, 2.5-, 6.0-, 12.0-, 20.0-, and 25-MW_e generating units. Self-contained geothermal modular thermal power plants with a 1.7-MW_e and 20-MW_t power, respectively, can be regarded as virtually completed. Thermoelectric power plants of any capacity can be assembled from these generating units.

Bioelectric Power Engineering

This scientific and engineering trend entails the development and design of the methods of solar energy and biomass conversion into fuel and energy as well as many useful substances, including feed additives, fertilizers, and drugs. The principal source of raw materials for bioenergetics are organic waste whose annual production in all industries of the USSR national economy was estimated by the USSR State Committee on Science and Technology (in 1986) to be in excess of 500 million tons of dry substance. This includes 230 million tons of livestock and poultry farm waste, 160 million tons of plant-growing waste, 70 million tons of timber and lumber yard waste, 60 million tons of solid residential waste from urban and rural areas and the industry, and 7 million tons of waste water sediments; their reprocessing using existing technologies will make it possible to obtain 150 million tons of equivalent fuel.

There are three different methods of biomass processing into fuel:

first: bioconversion or breakdown of organic substances of the vegetable or animal origin under anaerobic (without air intake) conditions by special types of bacteria with a development of gaseous fuel (biogas) and or liquid fuels (ethanol, butanol, etc.). Bioconversion also includes production of thermal power during the aerobic microbiological oxidation of organic substances. These are the scientific buzzwords for composting and compost heating known to every gardener:

second: thermochemical conversion (pyrolysis, gasification, fast pyrolysis, and synthesis) of solid organic substances (wood, peat, and coal) into "synthetic gas" and methanol, synthetic gasoline, and charcoal; and

third: waste combustion (chips, mill cake, and lignin) in specially designed boilers, furnaces, and bonfires. Burning wood in household stoves can be classified as pertaining to this method. Yet wood, for some reason, has been excluded from the concept of biomass even though wood accounts for one-sixth of annual fuel consumption in the world, and approximately one-third of all felled trees is used for cooking food and heating. The total wood fuel consumption probably exceeds the level indicated in world statistics by threefold. Yet one-half of the world population are using primarily firewood for cooking food (which is four-fifths of the household energy consumption) and for heating.

The first biomass utilization trend (by conversion) is associated with methods of processing agricultural production waste, solid urban waste, and urban waste water sediments in industry. This trend is directly involved in solving today's three principal problems:

• environmental--preventing the soil, water, and air pollution with waste, especially livestock and poultry farming;

• alimentary (food)--production of high quality fertilizers (during anaerobic fermentation, nitrogen and phosphorus in the manure are fully preserved, while 30-40% is lost when manure is traditionally spread in the fields), feed additives, and preparations; and

• energy--biogas production (70% methane and 30% carbon dioxide with a combustion heat of 14,650-25,100 kJ/nm^3).

The total volume of livestock farming and plant-growing waste production in Russia is 20 million tons of dry substance; when these are fully processed, 35 billion m^3 of methane or 60 million tons of equivalent fuel can be produced.

Yet here, this trend has been virtually stuck in the experimental phase. Approximately 10 large bioenergy power plants (BEU), both domestically and locally produced, which process livestock and poultry farm waste, are in private operation today. Of all the plants constructed in Russia and in all republics of the former union, personal-use bioenergy power plants operate most successfully in Pärnu, Estonia (at a pig-raising complex with 54,000 animals and a bioreactor volume of 6,000 m^3) and the bioenergy power plant in the OGRE state farm in Latvia (at a pig farm with 3,000 animals and a bioreactor with a 100 m^3 volume).

Using a development by the KTISM scientific production association (today in Ukraine), in 1985 the Shumikha mechanical engineering plant (in Kazakhstan today) manufactured a KOBOS-1 bioenergy power plant intended for installation at medium-size farms (with 400-500 heads of cattle). After two years of testing, this installation was adopted for mass production.

The installation includes the following components: the manure shredder, a curing heater with a 25 m^3 volume, two horizontal methane tanks (bioreactors) with a 125 m^3 volume each, a gas holder, a hot water boiler, pumps, heat exchangers, a process monitoring and control system, pipelines, and auxiliary valves and fittings.

The initial mass with a 95-98% moisture content is shredded beforehand, heated, cured for one day, then delivered into one of the methane tanks where a 40-42°C temperature and a reduced pressure are maintained (300-500 mm H_2O). The daily charging batch is 20-25% of the single methane tank volume.

The production process at the KOBOS complex makes it possible to produce biogas with a combustion heat of 14,650-25,100 kJ/nm^3 (92-96,000 kJ/kg); in other words, a 2 m^3 biogas volume from one cubic meter of the bioreactor volume per day, 25-40% of which is used for the unit's housekeeping needs, while the remaining gas for the user. In foreign units, this "excess" gas is used for operating diesel-powered generators converted for running on gas. In the KOBOS unit, this is stipulated only on paper, so in many operating units, excess gas is simply bled off into the atmosphere. A BEU-202 unit with roughly the same design was developed by the Scientific Production Association imeni Frunze in the town of Sumy. Both plants did not require substantial modifications, yet the need to modify individual assemblies was not the principal reason for the total failure of the bioenergy power plant production program--only about 10 units were produced in 1987-1990 vs. 240 complete units called for by the plan. This failure was due to the fact that the original wholesale price of the KOBOS unit--170,000 rubles--rose to 350,000 rubles by 1989, while the total cost of the project, including construction, increased to one million rubles. Such cost of constructing the one unit was more than even the most economically sound collective and state farms could afford. To implement bioenergy power plants, the state had to pay for at least 50% of the total cost. This was not done despite numerous statements affirming the need to help the countryside.

In addition to improving the above units, bioenergy power plants for medium-size farms (by the All-Russian Institute of Rural Agricultural Electrification and Biomass Scientific Research Center, and Municipal Services Academy imeni Pamfilov) and private farms (by the All-Russian Institute of Rural Agricultural Electrification and Biomass Scientific Research Center) were developed in Russia in 1992.

Much has to be started from scratch in this new phase. But due to the universally high prices, the effort is doomed to failure without state support.

The first trend of biomass utilization (bioconversion) involves efforts to develop a plant for enhanced growth of microscopic aquatic plants and their reprocessing into glycerol and liquid hydrocarbons; this activity is underway at the Renewable Energy Sources Laboratory of the Moscow State University under contract to the Russian Federation Ministry of Fuel and Energy.

It is expected that the installation will ensure a solar energy to biomass conversion ratio of 10% or, in terms of liquid fuel, 20 g/1 m² per day. At the same time, a food additive for fish is produced. An idea is being floated of developing a complex on the basis of nuclear and fossil fuel power plant cooling ponds which would supply liquid fuel and fresh fish.

As for the second biomass application trend--thermochemical conversion--one should mention the activities in the framework of the "environmentally clean power engineering" program which involved technology verification and development of large-scale production of thermal gas generators for reprocessing lumber waste into gaseous fuel.

These efforts are being carried out by the All-Russian Scientific Research Institute of Hydrolysis and the Forestry Academy using three installations scheduled for completion in 1995. A layer-type gas generator with a thermal output of 1.3 and 5 MW, is being developed in the framework of these efforts for reprocessing coarsely dispersed raw materials with an efficiency of at least 70% at a raw material moisture content of up to 60% (the Les system):

a cyclone-type unit employing polyfraction materials with a thermal capacity of 100 kW to 3 MW and a 70% efficiency with an up to 60% raw material moisture content (the Tsyklon system):

an installation with an external heating gas generator for producing gases with a high caloric combustion value and synthetic gas from biomass waste with a thermal capacity of 1 kW and a 65% efficiency at a 60% raw material moisture content (the Termolizator system).

In 1992, efforts were underway to develop small gas generator plants running on saw mill waste with a capacity of 16 and 4 kW.

At the same time, a 100-kW thermoelectric power plant running on biogas (at the Municipal Services Academy imeni Pamfilov, All-Russian Institute of Rural Agricultural Electrification, and Environmental Protection Association) and gas generator electric power plants with a 16-kW (All-Russian Institute of Rural Agricultural Electrification) and 4-kW (Moscow Aviation Institute) capacity were being developed.

It was expected that pilot operation of these installations would commence in 1993.

And finally, the third trend is waste combustion. We all admire foreign boilers and power plants running on saw mill and lumber yard waste in Finland, Sweden, the United States, Canada, and other countries.

Yet a 1-MW power plant with domestic equipment has been operating for 15 years in the town of Kharovsk in Vologda oblast utilizing saw mill waste. Boiler rooms with domestic and foreign equipment running on chips are also operating in this oblast. Developmental work on utilizing chips for combustion in boilers began in the past year.

Yet this endeavor calls for an analysis of existing developments and domestic and foreign experience and for making sound decisions regarding the trends of future activities.

The first 100-kW wind turbine generator in the world was built in our country in 1931, and it remained in operation until World War II. Yet the country was unable to capitalize on this success and especially start large-scale production of high-power wind turbine generators. It was only in the last two-to-three years that cautious optimism has been expressed in this area. What are the arguments in favor of wind power engineering?

First: Military industrial complex enterprises began serious work on the development of wind power plants (VEU), which serves as a certain guarantee of the technical level of developments and workmanship.

Second: The existing shortage of fuel and energy resources forces the captains of industry to look for ways of increasing the power supply reliability. Construction of wind power plants in combination with other energy sources is one of the realistic methods of resolving this problem.

And finally, the third: financial support of the efforts on part of the Russian Federation Ministry of Fuel and Energy and the Russian Federation Ministry of Science. Yet one should immediately add that this support is clearly inadequate.

Let us briefly touch upon the wind energy potential. The total kinetic energy of the wind over the planet is estimated on the order of $2.43 \cdot 10^{15}$ kWh. This figure exceeds the quantity of electric energy generated in the USSR in 1990 by roughly 100 times. The proportion of the wind energy which can be utilized cannot be easily estimated with confidence. It depends on the level of wind power engineering development, user capabilities, a combination of consumption modes and wind conditions, and the methods of storing the energy generated by the wind turbine.

Official estimates of the likely proportion of wind power engineering in the existing energy consumption structure of such countries as Great Britain and Germany may serve as a benchmark in determining Russia's engineering potential. The proportion of wind power engineering in these countries was estimated at 20%.

Technical wind energy resources in the northern part of Russia are estimated at 0.0005% of their potential. Nevertheless, the total installed capacity of wind power plants in this region may reach a figure of 700 million kW, while likely annual production--at 2,150 billion kWh, which exceeds the annual electric power production in Russia in 1991 ($1,066 \cdot 10^9$ kWh) by almost twofold. For Russia as a whole, generation my reach $1.4 \cdot 10^{13}$ kWh. Converted to equivalent fuel allowing for the utilization factor, this is equal to 1,670 million tons of equivalent fuel. By reducing this figure by two orders of magnitude, one can safely assume that the economic potential of Russia's wind power engineering is equal to 16 million tons of equivalent fuel.

Thus, Russia's wind power resources are enormous. Yet as we have already indicated, the cost of wind power plants and a lack of large-scale production, still make their wide-ranging implementation impossible.

What is the status with the development and setup of wind power plant production?

Under contract to the former USSR Energy Ministry, the Raduga Moscow Design Office was developing and planning on producing pilot generating units with a 1,000-kW and 250-kW capacity back in 1991 and beginning production of a prototype batch of these units and resolving the issue of their mass production in 1992. Yet the efforts were virtually frozen in 1992 due to the lack of funding. There is hope that the first pilot units will be fabricated and tested in 1993. Together with the Vetroen Scientific Production Association, the Yuzhnoye Scientific Production Association developed and in 1991 began production (almost one year behind the original schedule) of the first four prototype generating units with a 250-kW capacity, also under contract of the former USSR Energy Ministry.

It was expected that the 1,000- and 250-kW generating units by the Raduga Moscow Design Office and 250-kW units by the Yuzhnoye Scientific Production Association would be used to set up the first experimental wind power plant systems with a total capacity of 58.5 MW, including the Leningrad wind power plant on the Gulf of Finland coast (25 MW), Dzhungar wind power plant in Kazakhstan (15 MW), the Crimean wind power plant on the eastern coast of Crimea (12.5 MW), and Dagestan wind power plant near the town of Makhachkala (6 MW).

Today, the plans drawn by the republics of the former union are being changed, and it is difficult to assess the future of these projects. Yet the Russian Federation Ministry of Fuel and Energy is planning on additionally beginning construction of a 22-MW wind power plant in Kalmykia.

Turbine generators with a 1,250-, 250-, 100-, 60-, and 30-kW capacity (this was already described in issue No. 5 of our journal for 1992) are being developed under contract to the Energobalans Association for the development of wind power engineering (SOVENA Joint Stock Company).

The Yuzhnoye Scientific Production Association is the developer and manufacturer of the 1,250-kW generating unit (Yuzhnaya-1250 with a vertical shaft). It was expected that the prototype fabrication would be completed in 1992, and the initial batch production was planned for 1993; yet in 1992, work on this generating unit stopped completely.

[...] cooperation with other enterprises. The Scientific Production Association of the Leningrad Hoisting and Transport Machinery Plant (Lenpodyemtransmash) fabricated one version of this generating unit design in 1992; it is being assembled at the Novorossiysk wind power plant, while the second version is being manufactured by the joint stock company of defense enterprises in the town of Perm.

A 100-kW generating unit (VEU-100 M) was developed by the Ufa Aviation Engineering Institute. Together with aerospace industry enterprises in the town of Ufa, this institute's pilot production began fabrication of individual prototype assemblies, while its manufacture and assembly are planned for 1993.

The Tochnost Scientific Production Association in the town of Tula began the development of a 60-100-kW generating unit (VEU-60) and is planning on fabricating two pilot prototypes by mid 1993.

The Vetroen Scientific Production Association has developed and the Bashkortostan Department has upgraded a 30-kW wind power plant, so pilot prototypes were manufactured in 1990 by the Bashkiri machine building plant in Ufa. Yet subsequent work slowed down, and production of the 30-kW wind generating unit will switch to other enterprises.

At the same time, in 1990-1991, the Bashmashzavod Bashkiri machine building plant manufactured a batch (approximately 60 units) of 16-kW wind generating units and 30 more in 1992. Yet this generating unit was not properly developed and is capable of operating only with a heating (active) load.

Using the generating units developed by the Motorostroitel Motormaking Production Association in Perm and Lenpodyemtransmash Hoisting and Transport Machinery Plant in Leningrad (200 kW) as well as the Ufa Aviation Institute (110 kW), the Energobalans Association for the Development of Wind Power Engineering (SOVENA Joint Stock Company) began in 1992 developmental work on several wind power plants, including the ones on Cape Dikson (12 MW), in Novorossiysk (15 MW), in Yakutia (25 MW), and in a number of other places.

The Vetroen Scientific Production Association is mass producing a 4-kW wind power generating unit with an annual production volume of 300-400 units. Yet these units are characterized by low workmanship which prevents their wide-ranging applications and harms wind power engineering.

The Motorostroitel Motormaking Production Association in Rybinsk is proposing production of 4-kW wind-driven generating units (developed by VETEN).

The Aeromekhanika Joint Stock Company in Perm has begun production of 3-kW wind turbine generators.

The Vetroen Scientific Production Association is also developing and fabricating a number of water-lifting, wind-driven electric and mechanical plants with a windwheel diameter between 1.2 and 6 m; their annual production volume is within 1,200-1,500 items. Today, all this production is in Kazakhstan.

Many organizations and enterprises are attempting to develop and manufacture low-power, wind turbine generators. These include the Moscow Aviation Engineering Institute, the VETEN Cooperative in the town of Istra, the Yakor Scientific Production Association in Moscow, the All-Russian Institute of Rural Agricultural Electrification and the Azimuth Leningrad Scientific Production Association in Gatchina, Energiya Scientific Production Association in Voronezh, and the Vetroen Scientific Production Association.

The possibility of wide-ranging implementation of low-power, wind turbine generators is largely dictated by the availability of storage batteries and charging devices.

As the wind turbine generator power increases to 1 kW and higher, the complete plant set should include in addition to the storage battery and the storage devices (a rectifier) an off-line inverter which will make it possible to power 220 VAC household appliances. This is what the most foresightful developers are doing today.

Let us quickly examine what is being done in the West in the field of wind power engineering. As of early 1991, the total number of operating generating units in the State of California alone (United States) exceeded 15,000, and their total installed capacity reached 1,400 MW and annual generation--2.1 billion kWh.

Denmark's achievements are impressive. Thus, as of 31 Dec 91, the total number of wind power plants connected to the grid (owned privately or collectively) reached 3,218 with a total installed capacity of 418 MW which generated 740 million kWh during the year.

[947F0156c No 4, Apr 94 pp 18-21]

[Excerpt] Let There Always Be Sun...

Let us examine the problems facing solar power engineering.

We should start by noting that this type of power engineering has the highest growth potential among all traditional and nontraditional sources. It reaches $123 \cdot 10^{12}$ tons of equivalent fuel a year for the entire surface of our planet, which exceeds today's energy consumption level in the world ($0.01 \cdot 10^{12}$ tons of equivalent fuel) by more than 10,000 times. For Russia, the annual growth potential can be estimated by a figure of $3.25 \cdot 10^{12}$ tons of equivalent fuel.

Naturally, surface irradiance depends on the geographic latitude and the season. During the summer solstice at a 50° latitude (June-July), it reaches more than 9 $kW \cdot h/m^2$ per day, while during the winter solstice--1 $kW \cdot h/m^2$ per day. The figure for the year is approximately 2,000 $kW \cdot h/m^2$. For an area located on the equator, regardless of the season, irradiance amounts to slightly more than 7 $kW \cdot h/m^2$ per day.

Technical potential depends on the solar power plant efficiency, the solar radiation lever, user operating conditions, energy storage capabilities, etc.

At today's photovoltaic cell efficiency of 10%, one can "take-off" only 200 $kW \cdot h/m^2$ per year. In all, one can tentatively assume the technical potential of the solar power industry to be equal to 0.1% of the gross potential, which amounts to approximately 3.25 billion tons of equivalent fuel.

According to data gathered by the All-Russian Institute of Rural Agricultural Electrification, the maximum feasible installed solar power plant capacity in a consolidated power grid may amount to 15% of the total capacity, or 40 million kW. We should note that this would call for occupying an area equal to 400 km^2 or 0.0024% of Russia's territory.

In the Russian Federation, the most favorable regions for construction of solar power plants capable of a specific electric power generation of 200 kWh/m^2 or more are the following: Astrakhan, Volgograd, and Chita oblasts, the maritime kray, Greater Sochi, Kalmykia, Dagestan, Tuva, and Buryatia.

Solar Power Engineering Development Trends

There are two trends in utilizing the power of solar energy: converting it into electric or thermal power.

Solar power units, in turn, are divided into three principal categories. In the first, solar power heats water or any other working medium to a vaporous state, then the vapor is directed to a turbine which spins an electric generator (the steam turbine cycle). In the second, solar power is utilized for heating the working medium in a special thermal engine (Stirling type) which drives the generator rotor (rotational or reciprocating). In the third, photoelectricity is used--the commonly known PV arrays.

An example of the first type of installation is the electric power plant in Crimea (SES-5) with a 5-MW capacity which was built by the USSR Ministry of Power and Electrification and commissioned in 1985. A group of enthusiasts led by F.V. Sapozhnikov accomplished the almost impossible--using virtually handmade tools, it developed and fabricated new equipment and completed all necessary construction and erection operations. Yet enthusiasm alone was not enough for all this. They were unable to implement the design station performance, so the principal design indicators--generation and cost of production--were not reached. At the same time, the six years of station operation provided vast materials for developing more modern solar power plants which will undoubtedly be utilized in the future. The most important outcome of the power plant operation was in training a skilled team of operating personnel who share a unique experience and also determine the ways of improving these types of stations.

The second type of power plants with a Stirling engine has been developed at the Astrophysics Scientific Production Association under contract to the former USSR Energy Ministry. They have a power of 2.5 and 5 kW and a reflector diameter of 5 and 7 m, respectively (for concentrating solar radiation in the engine receiver). Such power plants could be used as self-contained power supplies as well as modules for large solar power plants. The Astrophysics Scientific Production Association is prepared to manufacture them--they are waiting for orders.

Solar arrays are known because of space vehicles; yet on the ground, there are photovoltaic plants with a power from tenths of a watt to 40 W. They are used for powering signaling devices, household appliances, and microscopic pumps and for boosting storage batteries. Among more or less large units, there are pilot prototypes of a photovoltaic power plant with a capacity from 0.6 to 3 kW, a solar water-lifting plant with a 1.2-kW capacity, and photovoltaic power plant for a residential building with a capacity of up to 3 kW.

The problem is that a ridiculously small number of PV cells is being manufactured--their total capacity reaches several hundred kilowatts per year (1992). Altogether, approximately 60 MW of PV cells is produced every year in the world, and there are a dozen electric power plants with a capacity of hundreds of kilowatts operating in power grids.

We need resources for developing the raw material base and setting up production.

Production of PV cells has been set up at the Moscow City Branch (MGO) of the "Kvant EMP agro" electromechanical production association, Scientific Production Association of Machine Building, and All-Russian Institute of Rural Agricultural Electrification. The Moscow City Branch of Kvant EMP agro managed to carry out a portion of a large-scale experiment to construct a "solar village" in the Chernomorskiy settlement of Krasnodar kray. Solar arrays with an up to 3-kW capacity were placed on the roofs of nine buildings connected to each other into a single network and linked to the power grid. The average daily electric power generation per unit was approximately 10-kWh which exceeds the standard demand of a family of four.

It would be appropriate to note that the need for self-contained small power plants on the basis of PV converters is so high that their cost is still not the main obstacle for their implementation. The problem is different--electric power plants intended for operation in power grids. Here, the specific quest of installed PV array capacity is the principal factor which determines the possibility of their wide-ranging applications.

Construction of a solar power plant in Stavropol kray with a 1.5-MW capacity which would include various modifications of modules is being planned under contract to the Electric Power Engineering committee of the Russian Federation Ministry of Fuel and Energy.

We would like to hope that implementation of the project will provide a powerful incentive for developing this industry.

The second solar power utilization trend is its conversion into thermal power. Here, several directions have emerged: a) warming up water for heating and hot water supply purposes; b) heating air in order to dry vegetables, fruit, and hay; and c) heat treatment of reinforced concrete. The implementation scale of the first two types of devices are determined by the production volume of the so-called solar collectors--devices which receive heat from solar rays and heat water or air. For example, a barrel of water painted black and exposed to blazing sun also serves as a solar collector, albeit highly inefficient. In order to increase the solar radiation utilization efficiency, collectors are executed in the form of flat arrays through which water passes in channels or tubes. The side facing the sun is painted black and covered with special glass, while the panel itself is encased in a heat-insulating housing. This helps to achieve the high solar energy utilization degree (an efficiency of up to 50%), so the water passing through it is quickly heated to 50-60°C. Yet collector production requires rather advanced technologies, precise stamping, automatic electric welding, vacuum deposition, anticorrosion coat application, etc.

One or two solar collectors may supply hot water to a bathroom shower in a rural home from spring to fall (and at a Moscow latitude--from April through October). Combined into groups, they can provide hot water for household purposes and nighttime heating between spring and fall for rest homes, lodging homes, scout camps, field camps, farms, etc. Somewhat modified units are suitable for drying grain, fruit, and hay and for other agricultural purposes. There are quite a few such units in Russia, especially in the southern regions.

There are operating systems with collectors with a total area of up to 300 m^2 in the form of solar auxiliaries for existing boiler rooms. They make it possible to shut down the boiler rooms for the summer season and to continue supplying users with hot water. Annual fossil fuel savings

from 1 m^2 of the collector area is as follows at various latitudes: at the St. Petersburg latitude--from 60 to 90, for Moscow--from 70 to 124, for Samara--from 90 to 160, for Volgograd--from 110 to 185, and for Sochi--from 125 to 195 kg.

Unfortunately, attempts to set up mass production of solar collectors with satisfactory quality have been unsuccessful. Given a total demand for Russia of 1.5-1.8 million m^2/yr, production hardly exceeds 20,000 m^2. Yet enterprises which are prepared to set up mass production within 3-4 months can be found. These include the Mitra scientific production enterprise, the Kalinin excavator machinery plant, and the ARKVES Association in Moscow. The representative of the Kovrov mechanical engineering plant told the author of this article that in 1993 the plant was prepared to increase the production of solar collectors of its own design from 5,000 m^2 to 100,000 m^2/yr.

So what is the problem? The plants which produce collectors and other equipment need orders to schedule a production program for the next few years. Yet in today's economic situation, nothing can be accomplished without active financial support from the federal and especially regional authorities. Solar power plant customers, be that private individuals or organizations, must ensure that some of their cost is paid from regional or federal energy conservation funds. Payment of up to 50% of the cost of the first (pilot) solar attachments to boiler rooms would enable the users to place large orders and would help the manufacturing plants to set up the necessary large-scale production and thus noticeably decrease the cost of their products. Then gradually, for the next five years, they can reduce the proportion of direct subsidies and raise their production to a level at which the collector price would become "affordable" for most users. What kind of subsidies are we talking about? It can be tentatively identified based on the following considerations. For Russia, the start-up production volume of solar collectors can be estimated as 100,000 m^2/yr.

Given a 10-12,000 ruble cost of 1 m^2 in October 1992 prices, the amount of subsidies underwriting 50% of the cost totals 500-600 million rubles per year. Then, as the production volume increases, the amount of subsidies may remain constant since the percentage of grants will be decreasing. Thus, we would be able to boost the production volume to 1.5-2 million m^2/yr in 3-4 years making it possible to ensure a fossil fuel saving on the order of 0.5 million tons of equivalent fuel by 1997. Of course, the problem is not simply in saving fuel. What is equally as important is to improve the living conditions of the population and satisfy its demand for hot water. The administration of the regions which experience difficulties with providing fuel to the population should utilize these capabilities.

Finally, let us mention the last solar power utilization trend--solar heat treatment of reinforced concrete which is the most technically developed and economically efficient trend in solar power engineering, yet which is being virtually ignored in mass media. Existing concrete "steaming" methods are highly energy-wasteful, and their substitution will yield a noticeable result. Savings for each cubic meter of reinforced concrete vary from 40 to 80 kg of equivalent fuel. In 1985-1988, institutes of the former USSR State Construction Administration and USSR Ministry of Erection and Special Construction developed the scientific and engineering principles of precast reinforced concrete assembly practices using solar power which make it possible to implement

them on a large scale in the southern regions of Russia. Several designs of seasonal treatment sites with a capacity of 20,000 m^3 of reinforced concrete product per year, mobile seasonal and year-round installations with an output of 4 and 10,000 m^3/yr, and finally, a design of a mobile all-year-round plant with a 24-30,000 m^3/yr capacity have been developed. Yet in 1990-1992, the total volume of fossil fuel substitution due to solar heat treatment of reinforced concrete amount to merely 50,000 tons of equivalent fuel, which is only 5% of its capacity.

Heated Compressed Air Production Unit

947F0157A Kiev ENERGETIKA I ELEKTRIFIKATSIYA in Russian No 3 (161), May-Jun 94 pp 47-48

[Article by A.V. Vakhlamov, Yevpatoriya Electric Network Enterprise, under the rubric of the "Nontraditional Methods in Power Engineering"; UDC 621.181]

[Text] Known units consisting of a fan and an electric air heater intended for warm air heating have a number of shortcomings: limited applications due to the poor heat transfer agent parameters and a high aerodynamic drag of the air heater. To eliminate these drawbacks, a unit consisting of a compressor, a safety valve, and an electric air heater was developed. Its principal component is a cyclone-type swirling electric heat exchanger intended for heating the air.

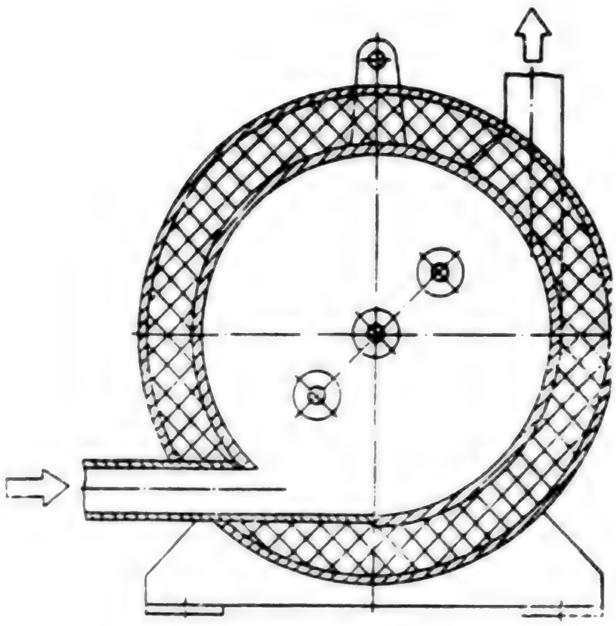
For the first time, this VAV-1 vortex machine was put into service at the SES-5 Crimean solar power plant in 1986, serving as an air heater in the equipment corrosion proofing system whereby the heat transfer agent parameters turned out to be adequate for drying the K-44-2s turbine and SPG 28-40 steam generator installed at an 82 m elevation above ground level.

Specifications of the VAV-1 Machine

Installed capacity, kW	2.08 x 3
Air output, kg/h	300-500
Cold air temperature, °C	25
Heated air temperature, °C	95
Air heating differential, °C	70
Number of tubular electric heaters	3

The vortical electric air heater consists of a cylindrical casing with tangential inlet and outlet heat transfer agent pipes which house a heating section consisting of three thermoelectric heaters (TEN). There is a heat insulating asbestos layer between the casing and the housing (see figure).

The heat exchanger is integrated with a unit for producing compressed air. i.e., a compressor. To enhance the heat transfer process. the flow is swirled in the air heater along its principal flow. Tangential heat transfer agent intake is used to decrease the aerodynamic drag whereby the delivery branch pipe is made as a converging tube.



Vortical electric air heater.

The first year of machine operation demonstrated that the corrosion rate of this unique basic equipment decreased by 50% relative to the preceding year when a prototype plant by the RIOA-TEP Riga Institute consisting of a low-head fan and electric coil heaters located in the delivery branch pipe was used: it turned out to be totally unsuitable for operation due to the poor heat transfer agent parameters.

The air heater operates by the following principle: compressed air is tangentially delivered through the inlet branch pipe into the housing and gradually expanding, performs a full turn without encountering local drag. The flow is slowed down due to the friction of its external layers against the internal rough surface of the housing whereby the air begins to heat up partially. The high heat transfer efficiency is attained not only due to swirling the flow and breaking up the boundary layer by local vortices developing directly near the finned surface of the heating section, but also due to the vortical effect itself, whereby the internal gas flow layers have a lower temperature than the peripheral layers, i.e., the "heater" is placed in the "cold" zone, which is responsible for the development of a considerable temperature flux which plays a positive role in this type of heat exchanger.

It is necessary to note that only the internal vortical effect is utilized in the VAV-1 air heater: in this particular case, it is less manifested than in vortex tubes with a flow separation by temperature.

This is accompanied by the flow velocity redistribution with a predominant flow rearrangement along the principal flow, i.e., the tangential flow velocity component decreases even more while the radial component changes its direction, so the air at the heat exchanger outlet near the heating section surface acquires a higher temperature than its peripheral layers, and finally, the axial component reaches the maximum.

When the compressor is turned off, the heating section is disconnected automatically since its starter coil is powered through the interlock contactor of the compressor's magnetic starter.

The heater capacity is controlled by disconnecting a certain number of thermoelectric heaters.

Summary

1. The seven-year VAV-1 operating experience since 1986 has demonstrated its high efficiency. The steam generator and turbine corrosion has been decreased by 50%.

2. The high heat transfer agent parameters, P of up to 0.6 MPa and T of up to 100°C make it possible to use the unit in production systems for various branches of industry.

Resistive Composites With Ordered Macrostructure in Low-Temperature Electric Heaters

947F0157B Kiev ENERGETIKA I ELEKTRIFIKATSIYA in Russian No 3 (161), May-Jun 94 pp 48-51

[Article by L.A. Griffen, Materials Science Problems Institute at the Ukrainian Academy of Sciences; UDC 621.039.546.535]

[Text] The economic efficiency of energy consumption largely depends on the efficiency of low-temperature heating devices since they consume more than half of the energy used in the national economy. Electric heating is characterized by its unusual efficiency since it makes it possible to enhance a number of production processes, make machines and equipment less materials-intensive, and improve their quality.

Yet the lack of the necessary building blocks constrains the expansion of electric heating applications. The industry mass produces virtually only one type of general-purpose heating elements--tubular electric heaters (TEN) [1] which, despite their advantages, often do not ensure the necessary technical and economic level of electric heating devices. Due to their shape, local heat release occurs in tubular electric heaters at a relatively high temperature. Yet a broad range of devices employing electric heating requires a uniformly distributed heat release or a heat release according to a given law (at a relatively low temperature).

With respect to the foregoing, research and development in the field of surface electric heating devices which may ensure a distributed heat liberation thus increasing the heating uniformity, decreasing the temperature differential between the heating element and the heated entity and, as a consequence, increasing the device reliability and lowering electric losses [2] have been given increasing attention in recent years. Such devices are developed primarily on the basis of resistive composite materials, the most efficient of which have current conductors executed as solid elements which are distinguished by highly stable electrophysical properties. Current conductors in these elements are connected into an electric circuit of a certain configuration located and fastened in an insulated warp in such a way that jointly they form a composite resistive material with an ordered macrostructure whose external insulation also serves as an integral part of the composite in a number of cases.

The most significant moment in production practices for such resistive composites is uniform distribution of the conducting elements on the insulating warp which often involves considerable difficulties. Here, mechanical technologies of fibrous materials which makes it possible to produce such resistive materials by combining linear conducting elements with insulating elements directly during the textile cloth fabrication have the greatest capabilities since a peculiar semi-regular product with a limited tendency toward segmentation is formed in this case.

There are traditional and untraditional new methods of fabricating fibrous materials which make it possible to produce flat resistive flexible materials with specified properties. When using traditional practices, linear elements (threads) are introduced into the insulating base and are fastened to it by a certain mutual intertwining. This ensures a uniform distribution of conducting elements on the flexible flat warp and their reliable mechanical restraint as well as external electric insulation and isolation of individual elements from each other in addition to the necessary internal electric connection circuits which provide a broad range of electric properties. When products are made using the new methods, however, only the conducting threads are arranged regularly, while the remaining composite system elements are [...] characteristics, but this significantly increases the basic equipment productivity. Composite resistive materials with an ordered macrostructure and continuous conducting elements (threads) are divided into the following categories: woven cloth, knit cloth, braided cloth, and non-woven cloth [4].

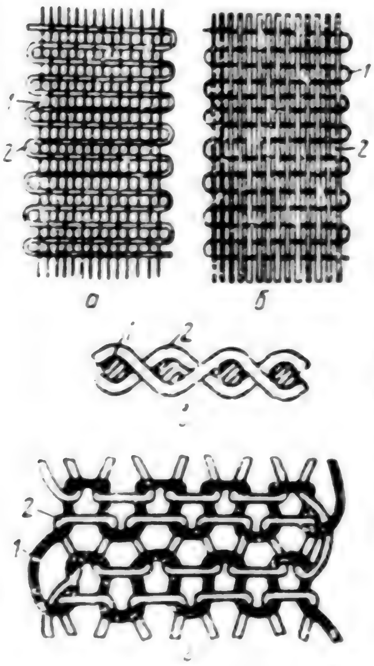


Fig. 1. Types of resistive composite materials with ordered macrostructure (From top left): a--Warp heater; b--Weft heater; c--Heating element cross section; d--Knit heater; 1--Heating element; 2--Insulating thread.

A few types of such materials are shown in Fig. 1. In the simplest heating fabric structures, the conducting element is positioned in the longitudinal direction (in the warp in Fig. 1a) or in the transverse direction (in the weft in Fig. 1b). Adjacent branches of the heating element may be separated by insulating threads of the additional weft or warp whose number depends on the requisite spacing between the branches. There may be no separating threads if the heating elements are positioned tightly. In this case, the heating element branches are isolated from each other due to the intersecting threads from the other system. Fig. 1c shows how intersecting insulating threads prevent the heating element branches from coming into contact with which other.

In addition to the warp and weft classification, there are a number of other classification criteria to these types of heating materials.

They can be fabricated in the form of bands made by ribbon looms as well as heating cloth made by wide looms. The heating ribbon width, as a rule, does not exceed 80 mm, and the heating cloth width, depending on the equipment used, reaches 1 m or more, and there are no limitations on the length of such materials [5].

The electrophysical properties of such materials (i.e., electric resistance, electric insulation, etc.) as well as their operating temperature are determined by the material structure which, in turn, depends on the structure of the insulating warp which ensures fastening of the heating element in it with a given density, the requisite mechanical strength, and reliability. Moreover, the principal structure of parameters are the type of intertwining, the heating element spacing, its structure, and the type of materials used.

The intertwining of the threads in the fabric determines the mutual position of the warp threads and shoot wires relative to each other. The heating band and fabric weave is selected on the basis of the requirement of the heating element spacing in the fabric and the strength of its fastening, the requirements imposed on the heating device, and from production considerations. Among all existing fabric weave types, linen and twill weaves and combined and complex weaves, primarily multilayered, are used.

The fabric texture is determined by the number of threads per unit of its length or width. An analysis of the fabric or tape parameters is primarily reduce to determining the heating element density. The heating cloth resistivity (resistance per 1 m of length) can be determined by the expression

$$R_y' = \rho' (1 + (1 + \alpha) \ 100) b \Pi_{н.э} = R' L,$$

where R'_y is resistivity, Ω/m; R is the resistance of a cloth segment with a length of L, Ω; ρ' is the heating element resistivity, Ω/m; α is the heating element strain where $\alpha=[l-b]/l]\cdot 100\%$; l is the length of the heating element branch, cm; b is the cloth width, cm; and Π is the heating element spacing density, cm^{-1}. Thus, given a specified cloth width, its resistivity may be changed by manipulating the heating element spacing density and its resistivity which, in turn, depends on its material and dimensions.

Given a warp (or base) heating element conducting thread positioning, they can be located in groups with insulating gap between them. Given n such groups connected in series and consisting of m conductors connected in parallel, the total heating element resistance over a heating cloth length will be equal to

$$R_0' = \rho' Ln/m.$$

A heating cloth section, as a rule, is rectangular in shape, yet the heating tape can be made curvilinear by using a warp material with anisotropic shrinking properties at elevated temperatures; this is accomplished by special heat treatment. Such a tape can be used in heaters for heating shaped surfaces, i.e., at the base of the pressing iron, in shoemaking machines, etc.

The structures of tapes with weft heating element positioning usually do not ensure external electric insulation; therefore, it must be developed in assembling the heating device on the heated entity. Today, the industry produces heating tapes with a 27-mm width and 40-mm length with a weft heating element arrangement which have a resistivity of between 300 and 1,000 Ω/m at an operating temperature between 400 and 600°C.

Tapes with a warp heating element arrangement are characterized by multilayer structures which make it possible to ensure a uniform conducting thread distribution in the width, the necessary electric insulation, and reliable conducting thread fastening under mechanical and thermal strain. Such bands usually employ conducting wire threads with a relatively large diameter which do not deform during processing.

Broadcloth resistive materials have both warp and weft heating element arrangements, yet experience shows that the latter is more expedient both from the process and design viewpoints. The structure of such heating materials is characterized primarily by the presence of several systems of warp and weft wires. Moreover, one of the weft wire systems serves as the heating element, while the other--as the filling insulation weft. This makes it possible to produce areas free of heating elements thus expanding the material application capabilities.

Looms make it possible to weave heating cloth with one or more heating elements as well as sectioned heating cloth in which the heating element is alternately intertwined with the conducting warp wires located along the edges of the fabric, thus ensuring a parallel connection of the sections. The unit power of a sectioned heater at a specified value of the power supply voltage U does not depend on the material section length and is equal to

$$P' = \frac{U^2}{\rho' l_c^2 [1 - (1 + a/100)] \Pi_{н.з} b_a},$$

where l_c is the heating section length and b_a is the active section width.

Knit cloth which incorporates conducting and insulating linear elements is another type of resistive material with an ordered macrostructure produced by mechanical technologies. As for any other resistive material, its most important parameter is resistivity. It depends on the characteristics of the heating element proper as well as on its location in the cloth which is determined by

the type of weave, heating element density in the weave, the type of loops, and the electrical connections which may be executed both during the cloth fabrication and later on.

According to their structure, such resistive materials can be divided into two categories in one of which most of the heating element is positioned rectilinearly, while in the other--the heating element is made in the form of loops. In this case, the loop shape largely depends on the similarity of the physical and mechanical properties of the insulating and conducting fibers.

Depending on the fabrication method, the resistive knit fabric can be either warp-woven or sunk-looped, according to the type and positioning of the loops in the weave; in the sunk-looped cloth, the loops made from the same wire are positioned in one loop row, while in the warp woven--in different rows. A sunk-loop resistive fabric in which the heating element forms the loops is shown in Fig. 1d.

There is a large number of knit weaves which make it possible to produce resistive materials with different electric characteristics and physical and mechanical properties. Although the structural diversity of heating fabrics produced on knitting machines is lower than that of woven fabrics, they have certain advantages over them: many structures can be stretched, production equipment has a higher output, etc. Nevertheless, they are used for surface-electric heating on a lower scale than the heating fabrics.

Pipelines belong to a class of engineering devices used extensively in various applications. In a number of cases, especially when it is necessary to transfer viscous and low-melting products, it is necessary constantly to maintain a given temperature which ensures normal progress of production processes. In other cases, there is an important task of preventing water or condensate from freezing in exposed pipelines at low external temperatures. Taped electric heaters are used for pipeline heating. Combined with the developed surface, the tape flexibility and length makes it easier to assemble the tapes and ensures a good heat transfer.

There are two methods of placing the heating tapes onto the pipeline. In the first case, the tape is laid along the pipeline in its lower section. Yet spiral tape winding on the pipeline is used more often thus ensuring its reliable fastening (Fig. 2a). This method make it possible easily to manipulate the electric parameters of the heaters by changing the heating tape length.

Likewise, heating tapes are used for heating pipeline valves, various types of vessels, etc.

A flat heater made on the basis of woven resistive materials is shown in Fig. 2b. It is intended for use in certain end effectors of process equipment. This material is placed between the electric insulation layers and is covered with a metallic housing. Such a heater has a sufficiently uniform

heat release distribution throughout the entire area. Because its operating temperature is under 600°C, it can be utilized widely in plastic processing equipment and in such processes as bonding, drying, curing, etc.

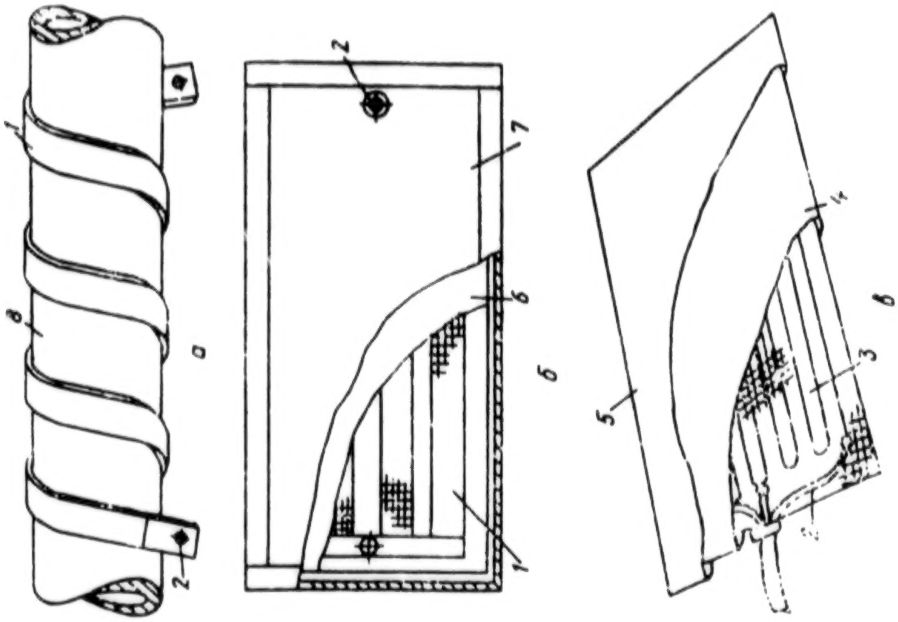


Fig. 2. Types of electric heating devices with distributed heat release on the basis of resistive composite materials with an ordered macrostructure: a--Pipeline heating by a taped electric heater; b--Flat electric heater; c--Household electric heater; 1--Woven heating tape; 2--Current lead; 3--Heating wire; 4--Electric insulation casing; 5--Pillowcase; 6--Insulation layer; 7--Housing; 8--Pipeline.

Because of their properties, it is especially expedient to use the above materials in the household. Such devices should ensure convenient operation, must be consistent with the health regulations, and should not create mechanical pressure and local heating as well as meet safety requirements. In most cases, one of the most important properties of these types of heating devices is flexibility; their second significant characteristic is a high heat release uniformity. Resistive materials with an ordered macrostructure, particularly heating fabrics and knit fabrics, meet all these requirements most fully.

For illustration, a household heating pad on the basis of a woven electric heater is used in Fig. 2c. The heating element in such heating pads is made from a heating fabric whose conducting wire is made from Kh20N80 wire with a 0.1 mm diameter. The heating element has a mid-point

terminal making it possible to achieve several power ratings and is placed into an insulating casing and a pillowcase. The heating pad ensures uniform heating and is convenient to use.

Summary

1. Expanding applications of electric heating require the use of new design solutions, particular composite resistive materials in the structure of electric heating devices and equipment.

2. One of the promising types of composite resistive materials includes flat, flexible materials with an ordered macrostructure on the basis of mechanical fiber material technologies.

3. Woven heating fabrics--heating cloth and tapes--are the most popular in electric heating devices.

4. The above materials make it possible to produce a number of highly efficient electric heating devices for various branches of industry and for household applications.

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